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APPLICATION

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TITLE: I/Q IMBALANCE CORRECTION

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IQ IMBALANCE CORRECTION

FIELD OF INVENTION

This invention relates to wireless data transmission.

BACKGROUND

In a QAM ("quadrature amplitude modulation") data transmission system, the in-phase ("I") and quadrature ("Q") components of a signal identify a symbol being carried by that signal. To transmit a desired symbol, the IQ components corresponding to that symbol must be modulated onto a carrier wave. In a direct modulation system, the IQ ratio is modulated by controlling the amplitudes of two sinusoids separated by ninety degrees in phase. When these two sinusoids are combined, the resulting signal defines a point (hereafter referred to as the "received point") in the IQ plane.

A set of constellation points in the IQ plane defines the set of symbols that can be transmitted. To the extent that a received point fails to align perfectly with a constellation point corresponding to the desired symbol, an IQ imbalance error may have been introduced.

The extent to which such IQ imbalance errors can be tolerated depends on the distribution of constellation points. For example, in a QPSK system, there are only four

constellation points, one in each quadrant of the IQ plane. As a result, so long as the IQ imbalance error leaves the received point in the correct quadrant, there is no symbol transmission error. However, in a modern 64-QAM system, sixty-four constellation points crowd the IQ plane. As a result, even a modest IQ imbalance error can easily place the received point near the wrong constellation point. This results in a symbol transmission error.

To increase data transmission speed, it is desirable to send several symbols at the same time. This can be achieved by concurrently transmitting each of several symbols onto carriers having different frequencies. To avoid interference between the carriers without consuming excessive bandwidth, the carrier frequencies are selected such that the peak of the spectrum of any one carrier coincides with nulls of the spectra of all other carriers. This technique, referred to as "orthogonal frequency division multiplexing" ("OFDM") enables several carriers to share a small bandwidth without interfering with each other. In the context of OFDM, these individual carriers are often referred to as "sub-carriers".

In a data transmission system, a variety of mishaps along the data transmission channel conspire to introduce IQ imbalance errors into the signal as it makes its way from the transmitter to the receiver. For example, as a result of aging, temperature effects, or imperfections in their design,

the electronic components that carry out modulation at the transmitter or demodulation at the receiver may fail to generate two sinusoids that are perfectly matched in amplitude and perfectly orthogonal in phase.

BRIEF DESCRIPTION OF THE FIGURES

FIG. 1 shows a data communication system;

FIG. 2 showsan equalizer;

FIG. 3 shows points in an IQ plane; and

FIG. 4 shows an adaptive filter.

DETAILED DESCRIPTION

The invention provides a method and system for adaptively calibrating a receiver to correct for IQ imbalance errors arising from direct conversion of a signal. As used here, direct conversion refers to both direct up-conversion, as performed by a transmitter, and direct down-conversion, as performed by a receiver. Since the receiver calibration is carried out without relying on information about the transmitter, the receiver can correct IQ imbalance errors with contributions from a variety of transmitters made by different manufacturers.

FIG. 1 shows a data transmission system **10** having a remote transmitter **12**, a transmission channel **14**, and a local

receiver **16**. Within the remote transmitter **12**, an IFFT block **18** generates a time-domain representation of an input signal containing the symbols to be transmitted. The IFFT block **18** provides this time-domain representation to an up-sampler **20**, the output of which is filtered by a transmitter filter **22**. The output of the transmitter filter **22** is then provided to a multiplexer **24** that modulates each subcarrier with one of the symbols to be transmitted. This multiplexer **24** introduces a source of IQ imbalance error.

From the multiplexer **24**, the subcarriers radiate from a transmitting antenna **26** and enter the transmission channel **14**. Along the way, they encounter additional sources of distortion. For example, reflections from obstacles can result in multipath errors. In some cases, the frequencies of the subcarriers may be shifted.

A receiving antenna **28** at the local receiver **16** captures the subcarriers, together with any white noise in the environment and any other interfering signals. This hodgepodge of signals is then provided to a demultiplexer **30**, which introduces another source of IQ imbalance error. The output of the demultiplexer **30** is provided to an anti-alias filter **32** and then to an inverse demultiplexer **34** whose function is to remove any IQ imbalance introduced by the demultiplexer **30**. The resulting signal is then provided to a

frequency-offset-correction block **36** to correct IQ imbalance resulting from frequency offset errors that exist because of any mismatches between the resonant frequency of an oscillator at the local receiver and the corresponding resonant frequency of an oscillator at the remote transmitter.

The output of the frequency-offset-correction block is then sampled by a down-sampler **38** and provided to an FFT block **40**. The FFT block **40** provides a frequency-domain representation of the signal to a channel-estimation-and-correction block **42** that removes errors resulting from multipath along the transmission channel **14**. This results in a received signal that, except for any residual IQ imbalance errors, is essentially identical to the input signal provided to the remote transmitter **12**.

The received signal is provided to an equalizer **44**, shown in more detail in FIG. 2. Within the equalizer **44** the received signal is provided to a symbol-decision block **46**. The symbol-decision block **46** then determines the constellation point in the IQ plane that lies closest, in a Euclidean sense, to the received point in the IQ plane.

FIG. 3 shows an exemplary IQ plane having constellation points **48** distributed throughout four quadrants. These

constellation points **48** represent the possible symbols that are understood by the data transmission system **10**. Also shown in FIG. 3 is a received point **50** corresponding to the received signal. As a result of IQ imbalance error, the received point **50** does not coincide with any of the constellation points **48**. Nevertheless, there does exist a constellation point **52** that lies nearest to the received point **50** in the IQ plane. This nearest constellation-point **52** is defined by a two-dimensional constellation vector **c** having components c_I and c_Q representative of in-phase and quadrature components of the nearest constellation-point **52**. This nearest constellation-point **52**, which is assumed to correspond to the symbol that the received point **50** attempts to communicate, forms the output of the symbol-decision block **46**.

Referring back to FIG. 2, the received signal is also provided to a multiplier **54**, which combines it with the output of an adaptive-filter system **56**. The output of the adaptive-filter system **56**, which can be represented as a 2x2 composite equalizing-matrix "W", is selected such that the equalized signal provided at the output of the multiplier **54** approximates the input to the remote transmitter **12**. The reason the equalizing matrix is a "composite" equalizing-matrix will be apparent from the discussion of FIG. 3.

A differencing element **58** receives the equalized signal and the nearest constellation-point **52** from the symbol-decision block **46**. The output of the differencing element **58** is an error signal indicative of the difference between these two quantities. This difference is characterized in FIG. 3 by a two-dimensional error vector ε, having components ε_I and ε_Q representative of in-phase and quadrature components, that characterizes the extent of the IQ imbalance. This error signal is then provided to a weight-update block **60**.

The weight-update block **60** then determines a new composite equalizing-matrix that, when used to generate another equalized signal, further reduces the magnitude of the error signal. The output of the weight-update block **60** is then provided back to the adaptive-filter system **56**, which then replaces its composite equalizing-matrix with a new composite equalizing-matrix as provided by the weight-update block **60**. This new composite equalizing-matrix is then used to generate a new equalized signal. The process continues until the magnitude of the error signal reaches a minimum or a pre-defined threshold. The error signal thus functions as a feedback signal for adjusting the composite equalizing-matrix on the basis of the extent to which the equalized signal differs from the nearest constellation-point **52**.

FIG. 4 shows in more detail the manner in which the

adaptive-filter system **56** uses both the positive and negative frequency components of the received signal to generate the composite equalizing-matrix. The adaptive-filter system **56** includes a first adaptive filter **62** for generating a positive-frequency equalizing-matrix from the positive frequency components of the received signal and a second adaptive filter **64** for generating a negative-frequency equalizing-matrix from the negative-frequency components of the received signal. The positive-frequency equalizing-matrix and the negative-frequency equalizing-matrix are then provided to a summer **66**, the output of which is the composite equalizing-matrix.

Within the weight-update block **60**, the four weighting coefficients that make up the composite equalizing-matrix are updated by incrementing the previous weighting coefficients by an amount proportional to the corresponding error signal and to the received signal. The constant of proportionality is selected to control the speed of convergence. A constant chosen to ensure rapid convergence is apt to result in an unstable system. Conversely, a constant chosen to ensure a stable system is apt to converge slowly.

In some cases, the IQ imbalance error is so great that the received signal does not correspond to the closest constellation point in the IQ plane. Multipath in the

transmission channel can, in many cases, cause IQ imbalance errors of this magnitude. In some embodiments, the local receiver includes a channel-estimation-and-correction block **42** to correct these errors.

In the specialized case in which the data conforms to the IEEE 802.11a standard, the method carried out by a conventional channel-estimation-and-correction block **42** interferes with the operation of the equalizer **44**. For example, to correct for multipath errors, the 802.11a standard provides a training signal that includes a pair of training bits for each subcarrier. One of the pair of training bits is associated with the positive frequency component of that subcarrier; the other is associated with the negative frequency component of that subcarrier. For half of the subcarriers, these training bits have the same sign. For the remaining half of the subcarriers, these training bits have different signs.

To accommodate this disparate treatment of different subcarriers in the training signal, the equalizer segregates the subcarriers into two classes and processes them separately. The first class includes those subcarriers for which the corresponding training bits in the training signal have the same sign. The second class includes those subcarriers for which the corresponding training bits in the training signal have different signs. IQ imbalance errors for

symbols carried by subcarriers in both the first and second classes are corrected in the manner described above. Segregating subcarriers into two classes in this manner prevents the multipath correction performed on the first class from interfering with convergence of an equalizing matrix for subcarriers in the second class, and vice versa.

Other embodiments are within the scope of the following claims: